SQT

exploring earth resources from space

COVER: *Apollo 9 infrared photography of California's Imperial Valley/Salton Sea area and Mexico. Political boundary stands out sharply. Vigorous growths of alfalfa, sugar beets and barley appear as bright red.*

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

A new view of Earth is required to cope with the problems posed by a deteriorating environment, dissipation of natural resources, advancing technology, and expanding population. This view must be more comprehensive than any man has had before. Moreover, Earth must be visualized in its entirety. The problems of the air-ocean-land system that support life are global and it is in getting global information that Earth-orbiting satellites excel.

Satellites can collect global data on the condition of the atmosphere and oceans, on agriculture and geology, and on man and all other living things. They can gather much data directly and they can acquire other information from unattended sensors on the Earth's surface.

Satellites provide views of the Earth synoptically— all at once. Large scale features and interrelationships are revealed in a single pictorial sweep of a vast area, taken under uniform lighting conditions; much detail and contrast might be lost in a mosaic made from airplane surveys.

After launch, satellites can gather information regularly and inexpensively as they swing around Earth. Their steady flow of data can help to keep maps and charts current. They can alert government, science and industry to conditions making it possible to exploit short-lived opportunities or avert imminent disaster. Moreover, satellites can acquire information from areas where other means would be expensive or hazardous.

Color photographs of Earth, both conventional and infrared, obtained by the Gemini and Apollo astronauts and the unmanned Applications Technology Satellites demonstrated the feasibility of satellite surveys for the benefit of agriculture, oceanography, hydrology, geology and cartography.

As a result, NASA is working with other organizations and nations on an Earth observation program. The program includes information gathering elements — on Earth's surface, in the air, by unmanned satellites in Earth orbit, and by the projected manned space flight Skylab program. Skylab is planned as an Earth orbital laboratory, manned by astronauts, to investigate the effects upon men of sustained space flight, to provide an opportunity for study of the Earth and celestial bodies, and to make technical studies of materials and processes in a weightless environment.

REMOTE SENSING

Satellites that gather information about the Earth use a technique called remote sensing. Remote sensing is acquiring knowledge about an object from a distance. A variety of instruments and techniques have advanced the art of remote sensing. Astronomers have been among the major beneficiaries of such techniques, using them to learn about stars, galaxies, and other distant celestial phenomena. Observing in the infrared, for example, astronomers may glimpse stars developing inside of opaque clouds of dust and gas.

Remote sensing is possible because everything in its own distinctive way absorbs, emits, or reflects electromagnetic radiation. Electromagnetic radiation is the means by which radiant energy is transferred through space or matter. Familiar examples are visible light, radio waves, ultraviolet and infrared radiation, and X-rays. Electromagnetic radiation differs from particle radiation which consists of protons, electrons, or the nuclei of atoms. Examples of particle radiation are Alpha rays, cosmic rays, and the radiation constituting the Van Allen Radiation Region surrounding the Earth.

An object's distribution of reflected or emitted electromagnetic radiation is sometimes called its spectral characteristics or its signature. This distribution not only differentiates the object from others but also can indicate its size, shape, density, surface regularity, moisture content, and other physical and chemical properties.

Nearly like our own eyes, conventional color photography can pick up the range of electromagnetic radiation that we call visible light. Actually, visible light (or visible radiation) consists of electromagnetic radiation with wavelengths of 4000 to 7000 angstroms. Visible light occupies a relatively narrow band of the electromagnetic spectrum which is a manmade scale for electromagnetic radiation. The spectrum covers wavelengths from .0001 angstrom (some gamma rays) to radio waves with wavelengths of a million kilometers.

The electromagnetic spectrum embraces such a vast range of wavelengths that their sizes must be expressed in different units of measurement, such as a micron (a millionth of a meter), a millimicron (a thousandth of a micron) or an angstrom (one hundred millionth of a centimeter).

Color photography from satellite heights can tell analysts many things. It can indicate vegetation, soil conditions, water depth, mineral deposits, and other matters with which mankind is vitally concerned. Urban areas tend to stand out, farm fields produce recognizable patterns and a recently cleared woodland is apparent.

Photography has been advanced to the point where photographs taken from satellite altitudes of as much as several hundred miles have a resolution of one foot. This means that the photographs can be processed to show Earth features as small as a foot across.

The visible light band is used in other than conventional photography for specific searches. A film and filter combination may be employed to shut out all but the desired wavelength. For example, experimenters may employ the green wavelength range (about 5000 to 6000 angstroms) which many consider best for obtaining maximum underwater detail.

However, the visible light band cannot tell all that we need to know. As a result, NASA is experimenting with sensors that show more about the Earth than meets the eye. One of them, for example, picks up infrared radiation. Infrared light covers a band of electromagnetic radiation with wavelengths of from 75 to 1000 microns. These wavelengths are longer than those of the visible light band.

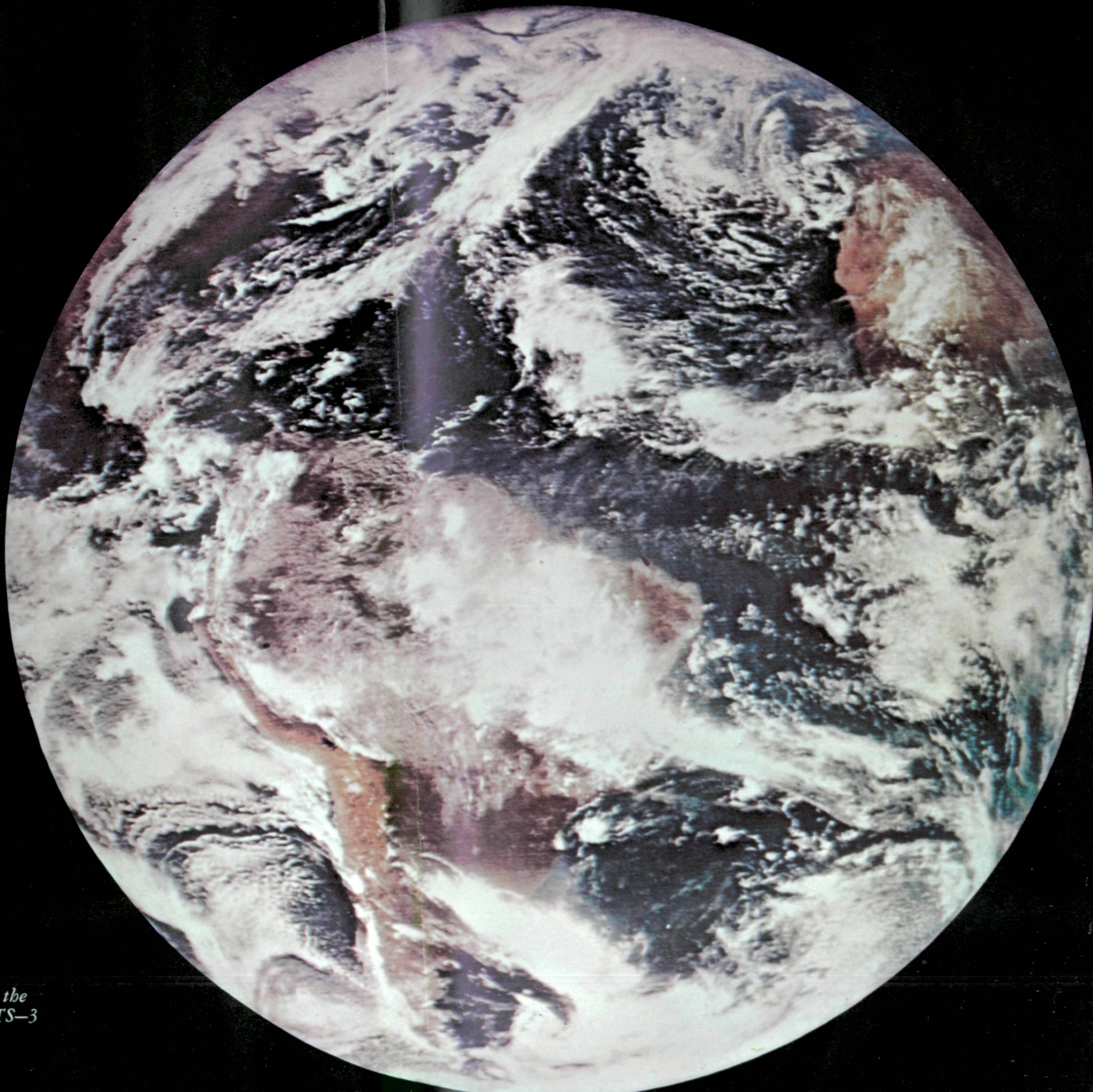
Infrared rays are invisible to the naked eye, but sometimes can be felt as heat. Actually, everything on Earth reflects or emits infrared rays, even the frozen polar caps. You create infrared rays in a multitude of ways; for example, lighting a fire, or starting your car.

Infrared rays can be picked up by a camera with infrared film (film sensitive only to wavelengths in the infrared) or by a radiometer (a radio receiver tuned to pick up and differentiate between infrared wavelengths). Both the film and the radiometer are capable of detecting not only faint infrared radiation but also minute differences in the wavelengths of the infrared band.

An Apollo 9 infrared photograph of the winding Mississippi River main channel shows recent changes in the river bed. The infrared radiometer of the Nimbus weather satellite enabled scientists to trace the course of the Gulf Stream northward through the Atlantic. Nimbus detected the slightly warmer temperature of the Gulf Stream as compared

Changes in the course of the Mississippi River are revealed by the presence of "oxbow lakes" and "meander scars" left from the former course. The photo was taken from Apollo 9.

Man interacting with his environment is creating severe pressures upon himself and upon the ability of the Earth to sustain and support him. The supply of such resources as land, water, food, minerals, air, and fuel is beset by the growing demands of a rapidly increasing population and swiftly advancing technology. If man is to survive and to maintain the quality of his life, he must find ways to balance his requirements against the Earth's ability to meet them.



A photograph of the Earth taken by the Applications Technology Satellite ATS–3

with the ocean waters. Infrared rays are also emitted from mineral deposits with varying degrees of intensity and at various wavelengths.

The use of radar waves, a part of the microwave radio band, is another way of studying Earth. Radar waves range from .54 to 140 centimeters long. Radar equipment is not passive like other sensors. It sends out a signal and then measures the way it is reflected. Radar can be used to look through vegetation at surface and subsurface geological formations. It can detect invisible traces of oil spills and satellite-borne radar offers promise of an all-weather coastal watch on possible oil-spill pollution. Radar can also indicate wave heights which are clues to ocean roughness and wind velocities.

Information about the extent of dangerous pollution in our atmosphere can be provided by satellites equipped with ultraviolet photometers. The photometer measures ultraviolet light absorbed or reflected, providing data on atmospheric constituents.

Ultraviolet light is electromagnetic radiation with wavelengths from 100 to 4000 angstroms. It is the part of sunlight that may cause our skin to burn during a day at the beach.

Ultraviolet sensors can indicate the presence and extent in our atmosphere of such invisible pollutants as sulphur oxides and carbon monoxide, millions of tons of which are emitted daily by industry and motor vehicles. Carbon monoxide is a familiar lethal gas, while sulphur oxides turn to sulphuric acid in the lungs, contributing to emphysema, bronchitis, and other respiratory ailments. Recent news reports have described the gradual destruction of priceless ancient architecture and sculptures in Italy when sulphur oxides in the atmosphere combined with rain water to form sulphuric acid.

Satellites can provide another system of oil spill warning with ultraviolet sensors. Oil spills stand out starkly on ordinary ocean water in ultraviolet light which also distinguishes between light and heavy oils. The light oils appear brighter.

Gamma ray sensors (one type is the familiar Geiger counter) have already been employed on spacecraft to study other celestial phenomena beyond our solar system. Employed on satellites, they could perform a number of useful functions.

Gamma rays emanate from nuclear reactions—the splitting or the fusing of atoms. They are the shortest of the electromagnetic waves, ranging downward to .0001 angstrom. As they fan out, they ionize the atoms or molecules with which they come in contact; that is, they strip away electrons which have a negative electric charge, causing the remainder of the atom (called an ion) to pick up a positive electric charge. The ions and the electrons then become particle radiations. Ionizing radiation alters genes or kills living cells.

Man is running out of fossil fuels and potential new water power sources for electricity. As a result, he is expected to turn increasingly to the use of nuclear electric generating plants. Gamma ray sensors on satellites can alert monitoring stations to radiation leakage from nuclear power plants, supplementing on-site safeguards. They can also prospect for new uranium reserves to fuel the nuclear power plants of the future.

CHOOSING THE BEST SENSORS

NASA experimentation is designed to determine the sensor output which offers the most reliable information indicator. For example, infrared film, rather than regular color film, appears best for use as a forestry early-warning system. On infrared film, diseased trees stand out in blue while healthy trees appear in red.

The reason that early damage to trees shows up clearly in the infrared, although not otherwise visible, is that healthy tree leaves have a high concentration of chlorophyl. Such tree leaves reflect more infrared rays from the Sun than the leaves of unhealthy trees that tend to have a low chlorophyl concentration.

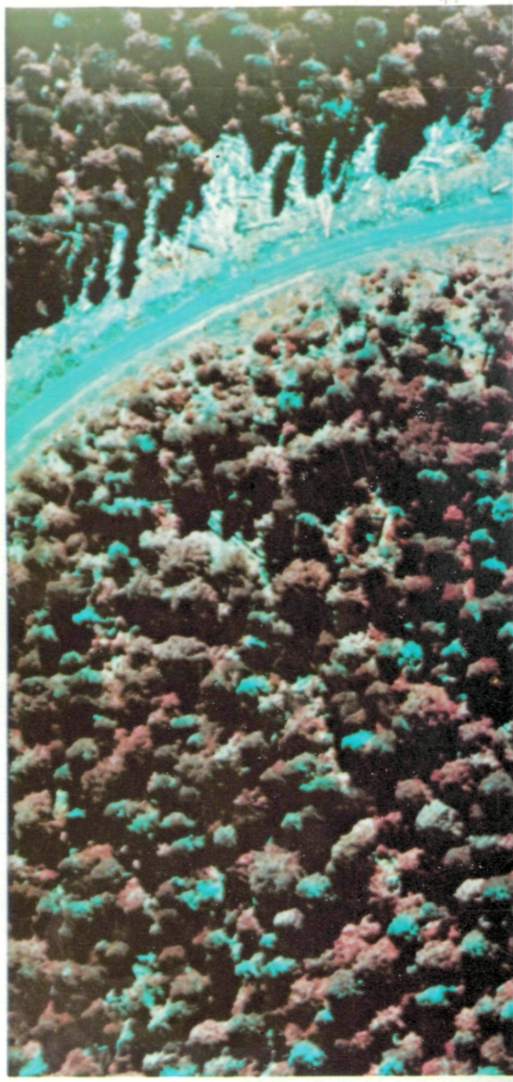
Since no single type of sensor is best for all surveys, NASA will employ multispectral, or multiband, sensing. This involves picking up different sets of wavelengths or frequency bands; for example, using films sensitized to green, red, and infrared light. The resulting complementary imagery, or composite picture, may contribute to identifying every important feature in an area.

FROM GROUND TRUTH TO SPACE TRUTH

A vital step toward a remote sensing capability is making space truth equivalent to ground truth. When the signature of an object is observed in place the signature (for definition see remote sensing) is called ground truth. The area where ground truth signatures are acquired is termed a test site.

For more than a half dozen years before launch of the Earth Resources Technology Satellite (see below), NASA has tested remote sensing techniques from aircraft. The goal was to achieve correlation of signatures obtained from overflights (space truth) with ground truth.

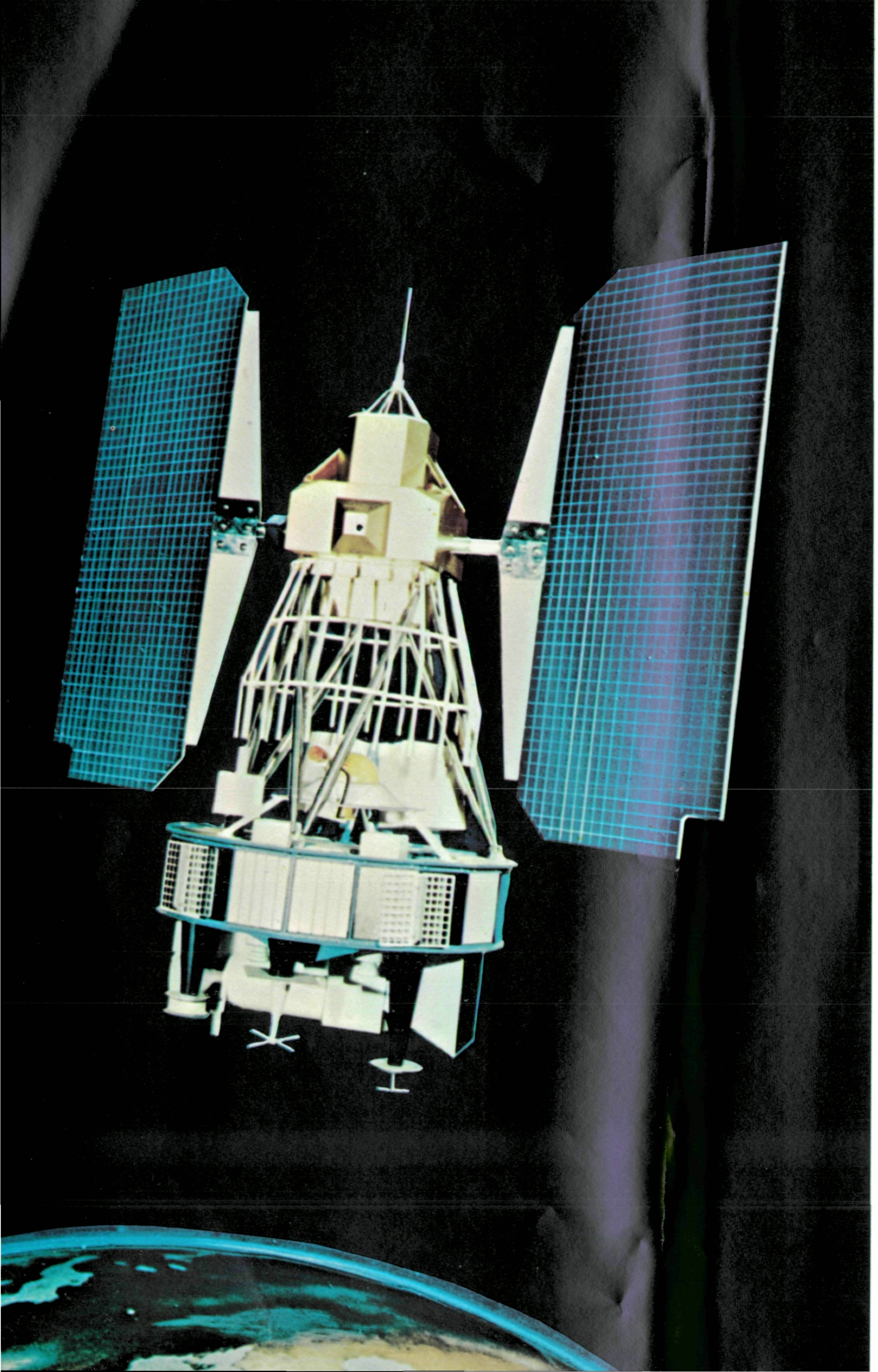
In the process of this testing, NASA's aircraft assisted the U.S. Geological Survey in a study of 1970 land use by obtaining high-altitude photography of 26



cities. The purpose was to correlate land usage with statistical data gathered during the taking of the census. Current experiments involve employment of aircraft at high altitudes to simulate coverage of the Earth Resources Technology Satellite over four different kinds of test sites:

- Arizona, including Phoenix and Tucson; study of arid lands.
- Feather River, California; study of hydrology.
- San Francisco/Los Angeles area; study of urban growth and agriculture.
- Chesapeake Bay on the Atlantic coast; study of ecology and oceanography.

The experiment provided substantive experience to scientists in Government agencies and universities who would later analyze comparable satellite data.



THE EARTH RESOURCES TECHNOLOGY SATELLITE (ERTS) PROGRAM

The ERTS program is the Nation's first space program to be devoted exclusively to a study of the Earth and its resources. ERTS will test new sensors and contribute to the principal technology required to carry out Earth surveys from space.

The two planned satellites weigh about 1800 pounds each. Structurally, they are modified versions of the Nimbus experimental meteorological satellite. Delta launch vehicles will rocket them from the Western Test Range, California, into circular, near polar orbits, about 575 miles above the Earth. In this orbit, they can observe every point on the Earth.

The satellites will carry television, as well as radiometric, scanners to obtain image data in various spectral ranges of visible light (red, blue, or green) and infrared. The spectral ranges will have been checked out earlier by aircraft and were also tested in an experiment aboard the manned Apollo 9 flight. Among the data to be obtained are information relating to crop species, crop health, types of rocks and soil, moisture content of the ground, coastal processes, surface water distribution, and water pollution.

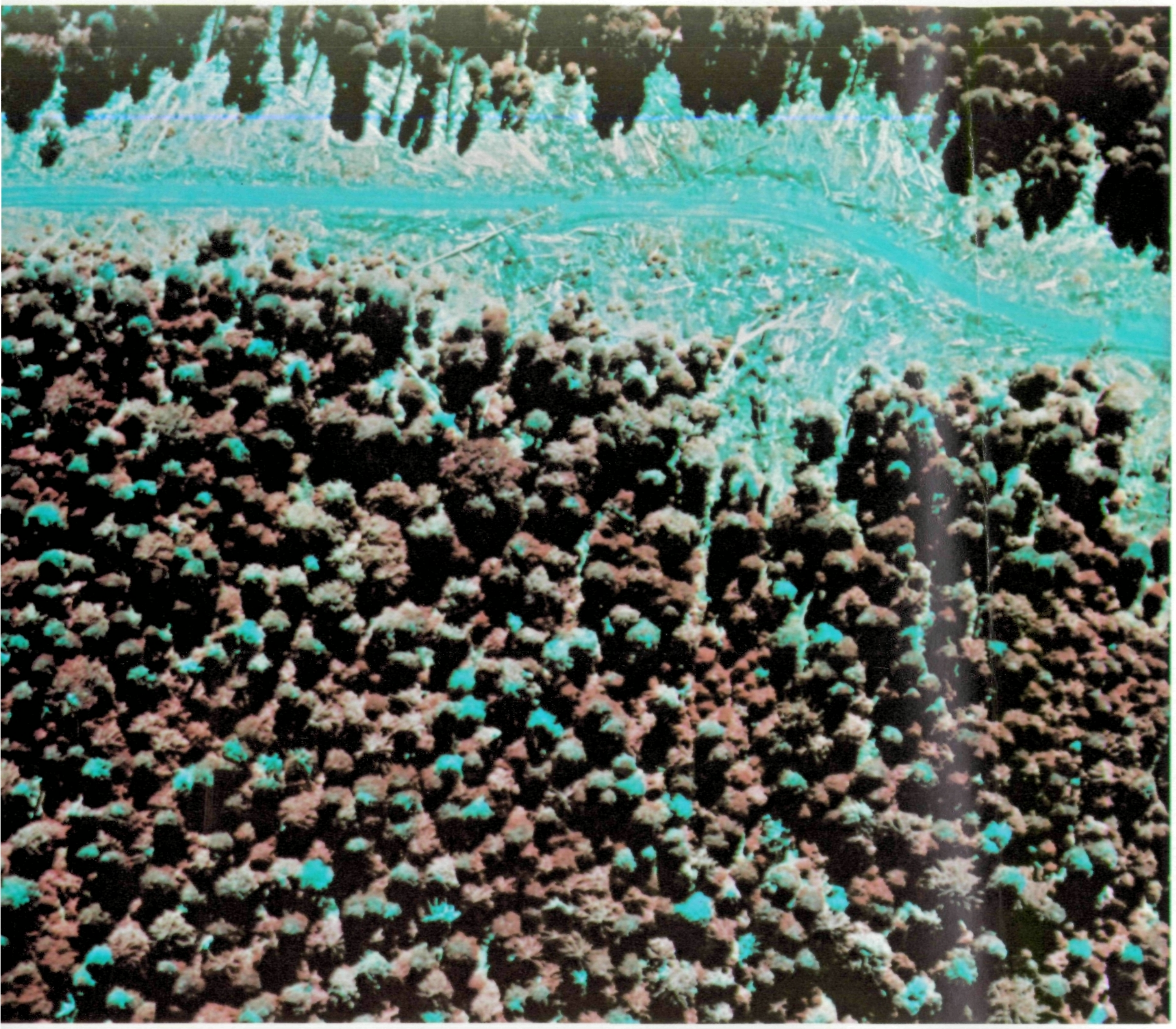
In addition, the satellites will carry receiver/relay equipment to collect data from ground-based remotely-located, and unattended sensors. The sensors are designed and emplaced to report ground truth on the water level of lakes, streams, and reservoirs; soil moisture content; snow depth; surface temperature; ocean salinity; ice pressure; ocean current; and atmospheric pollution. The satellites will gather this information from as many as a thousand different reporting stations and process and transmit the information to ground receiving stations.

The satellites will be three-axis stabilized and Earth-pointed so that they constantly aim their instruments at Earth. They are designed for a lifetime of a year to cover all four seasons and to account for seasonally-induced variations of information. The results of the satellite experiments will indicate the value and practicability of an operational satellite system.

The key tracking stations for acquiring data from ERTS are at Fairbanks, Alaska; Goldstone, California; and Greenbelt, Maryland. The Operations Control Center and Data Processing Facility for ERTS is at the NASA Goddard Space Flight Center, Greenbelt, Maryland. Goddard will make usable data available to interested agencies and principal investigators.

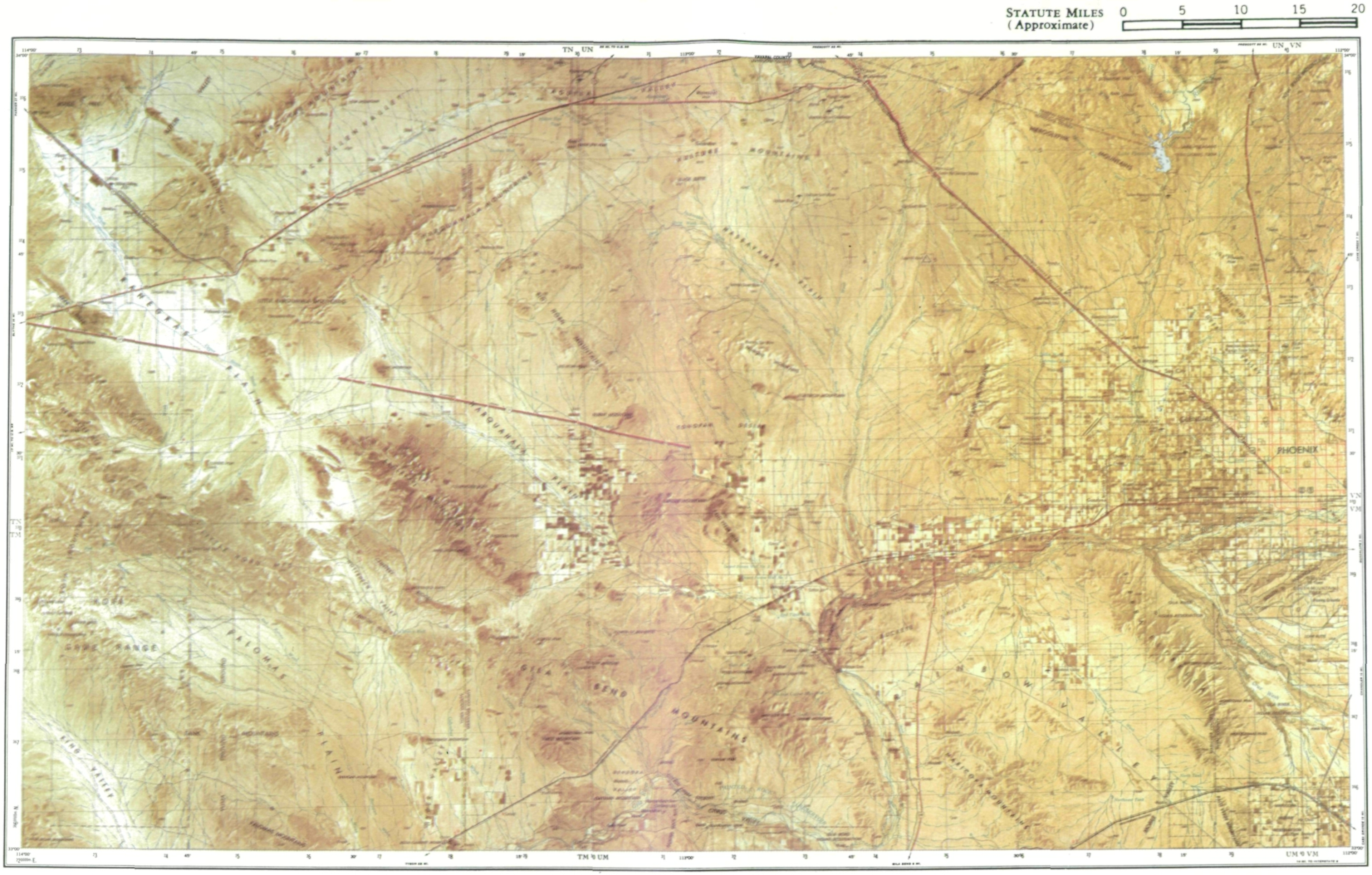
Earth resources program regional activity facilities have been established at several NASA field centers.

Artist's concept of the Earth Resources Technology Satellite (ERTS).



Infrared film shows insect-infested timber in blue, healthy trees in red.

Vegetation mapping of Phoenix, Arizona from an Apollo infrared photograph. The cultivated area registers as red squares. At left, the infrared photo; at right, infrared reflective vegetation extracted from the photo.



Experimental prototype map of Phoenix, Arizona made from two space photographs taken on Apollo 9. The photographs were rectified and fitted to the culture plate of a conventional medium-scale line map by the U.S. Geological Survey, in cooperation with NASA. Both exposures were made at an altitude of 127 Nautical Miles in March, 1969. By combining space imagery with portions of a conventional line map, the content, currency and accuracy of the conventional map is greatly increased.

MAPPING

There are so many Earth features to portray and the Earth's face changes so steadily that mapmakers currently produce some 100,000 new maps yearly. However, mapmakers find they have difficulty keeping their maps timely even in developed areas. For example, Florida's busy force of cartographers found on checking photographs from Gemini that their maps did not reflect many roads, bridges, and urban areas in the vicinity of John F. Kennedy Space Center.

In another case, a single photograph of the Salton Sea, in California, taken from a Gemini manned spacecraft provided more information than 500 aerial photographs. And it disclosed something new: a mysterious unknown swirl in the inland sea.

Nimbus, the experimental meteorological satellite, returned photographs of Antarctica that showed Mount Siple to be about 50 miles west of where other surveys had placed it. Moreover, the Nimbus pictures indicated that the so-called Kohler Mountain Range was non-existent.

Repetitive photography from spacecraft can show coastal changes and the movements of the main channels of rivers. Such information could contribute to future flood control and assist water transportation.

Until recent years, the cartographer's dream of mapping the whole Earth on a 1:1,000,000 scale seemed impossible of fulfillment. Now, satellites have brought this goal within reach.

Good maps are essential for mineral exploration, highway and pipeline routing, urban planning, and agriculture. An advantage of satellite photography is that it allows more rapid and accurate cartography than conventional systems. Because satellite photographs cover a larger area in a single picture, the number of individual pictures that have to be assembled into mosaics, and the labor required for such work, are reduced. Also, there are times when details present, but obscured, in a mosaic stand out in a long range photograph from satellite altitudes. Another advantage of satellites is that they can map areas where ground or aerial surveys are dangerous or expensive.

AGRICULTURE AND FORESTRY

World population has increased to a level where a critical need exists for effective management of agriculture and forestry on a worldwide scale. Prerequisite to effective management is accurate,

These are the Mississippi Test Facility, Bay Saint Louis, Mississippi; the Manned Spacecraft Center, Houston, Texas; Ames Research Center, Moffett Field, California; Wallops Station, Wallops Island, Virginia and the Goddard Space Flight Center, Greenbelt, Maryland.

Some near-term goals of the ERTS program and cooperating Government agencies are:

- To develop a land use map of the United States.
- Classify United States geologic and soil features by area.
- Develop an agricultural map of the United States.
- Collect data from remote, fixed stations having river gauges, fathometers, and other instruments.
- Advance ground computerization techniques to enable the flood of new data acquired to be quickly processed, interpreted, and applied to benefit man.

The ERTS program hopefully will open an era of new benefits from space technology as limitless as the frontiers of space itself. Some of the program's potential in several areas is presented later in this text. Beyond this, Earth surveys from space may have unanticipated potentials for benefiting mankind as significant as those already realized from the weather and communications sattelites.

SKYLAB

Skylab, a modified upper stage of the Saturn V launch vehicle, will serve as the Nation's first manned Earth-orbiting space station. One of the principal tasks of the Skylab program will be Earth observations and surveys.

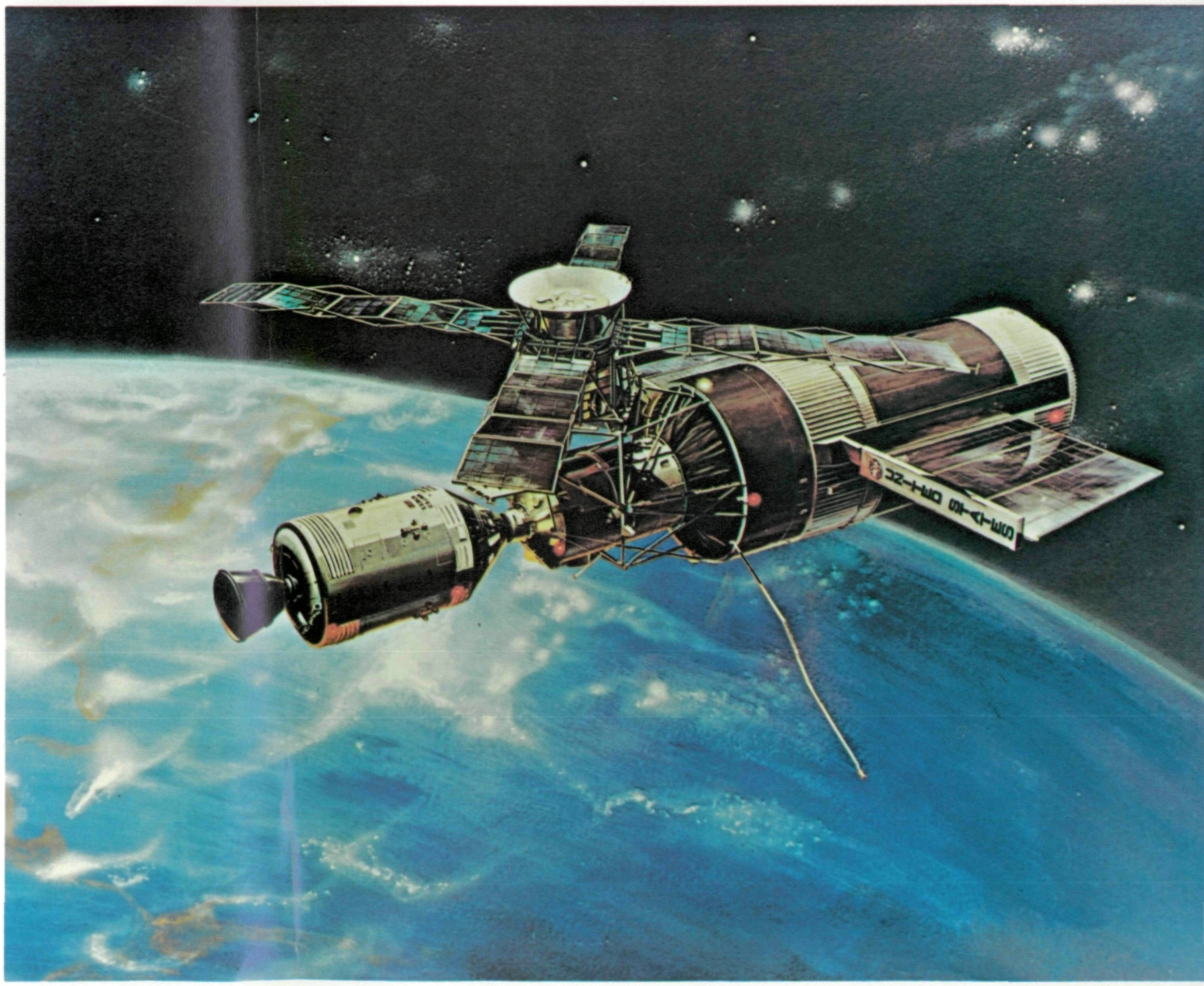
Astronauts in Skylab will contribute in this area by selecting and calibrating sensors, interpreting measurements rather than sending raw data to Earth, screening out irrelevant data, and detecting unforeseen events. An astronaut's capability to observe a large scene and to discern unusual features cannot be duplicated in current automated systems.

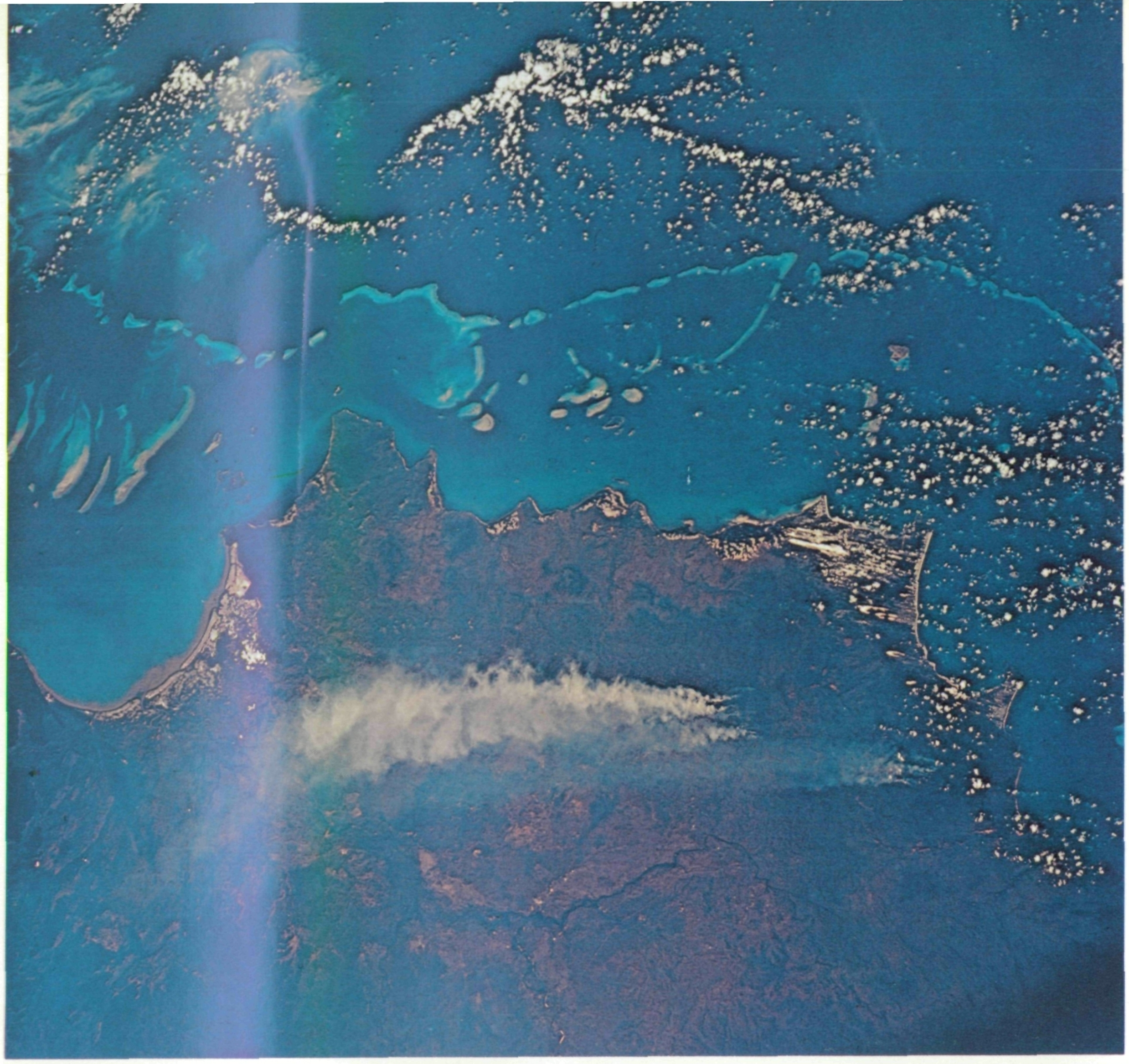
Among the contributions that Skylab will make to the Earth resources survey program is the operation of microwave sensors whose large antennas and high power requirements are beyond the capacity of the current generation of automated satellites. This experiment supports studies of such phenomena as ocean wave conditions, sea and lake ice, ocean clouds, snow cover, seasonal vegetational changes, flooding, rainfall, soil types and textures, soil moisture, heat output of metropolitan areas, and design of future more advanced microwave systems. Skylab will also provide broader spectral coverage. For example, its multispectral scanner will measure radiation in thirteen spectral bands as compared to the four-band ERTS scanner.

EARTH LABORATORY SATELLITE

NASA is conducting studies of an Earth Observatory Satellite (EOS), a satellite designed to continue and combine in one spacecraft the research and development functions individually performed by ERTS and Nimbus. EOS would provide data for research in Earth resources management and in meteorology and contribute to development of advanced sensors for observation of the Earth, its oceans and its atmosphere. The first EOS will place primary emphasis on oceanographic phenomena and on interactions of the ocean surface and the atmosphere. The relative inaccessibility of the oceans, their significance to meteorology, Earth resources, ecology and the environment and the availability of space technology for gathering information over the vast ocean areas combine to indicate the value of the EOS program.

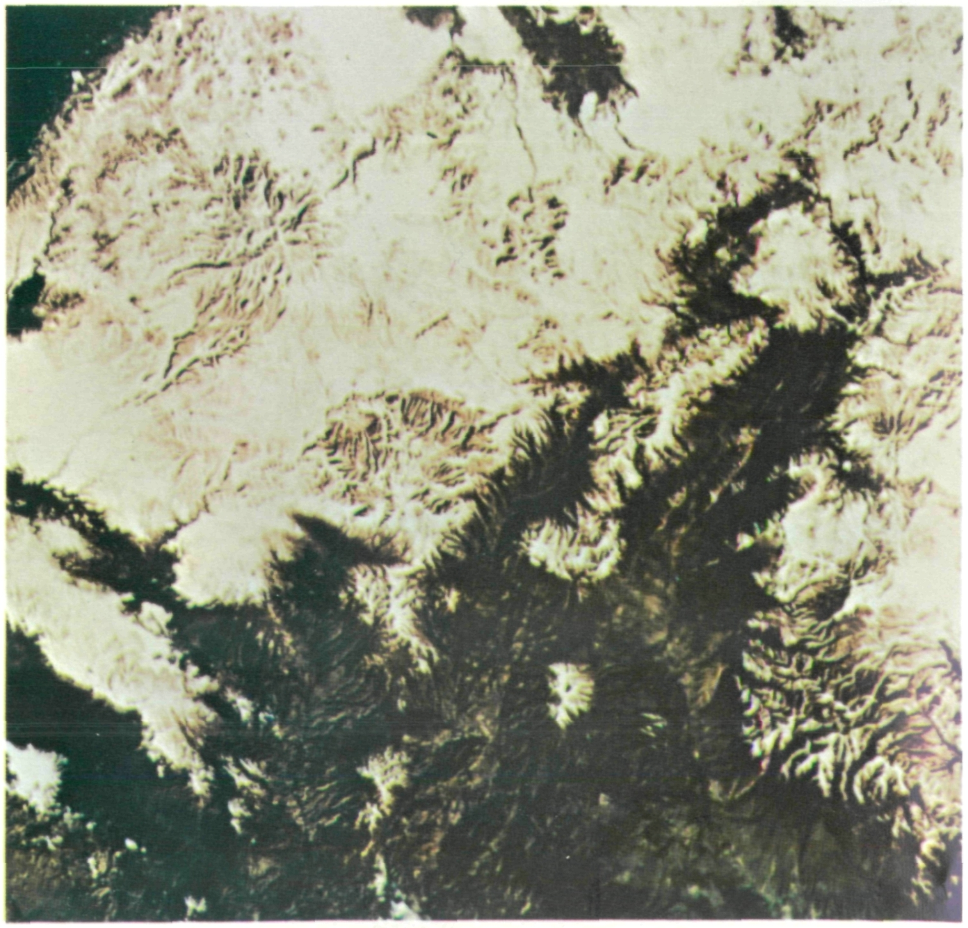
Skylab (artist's concept). One of the major tasks of the Skylab's crew will be Earth observations and surveys.

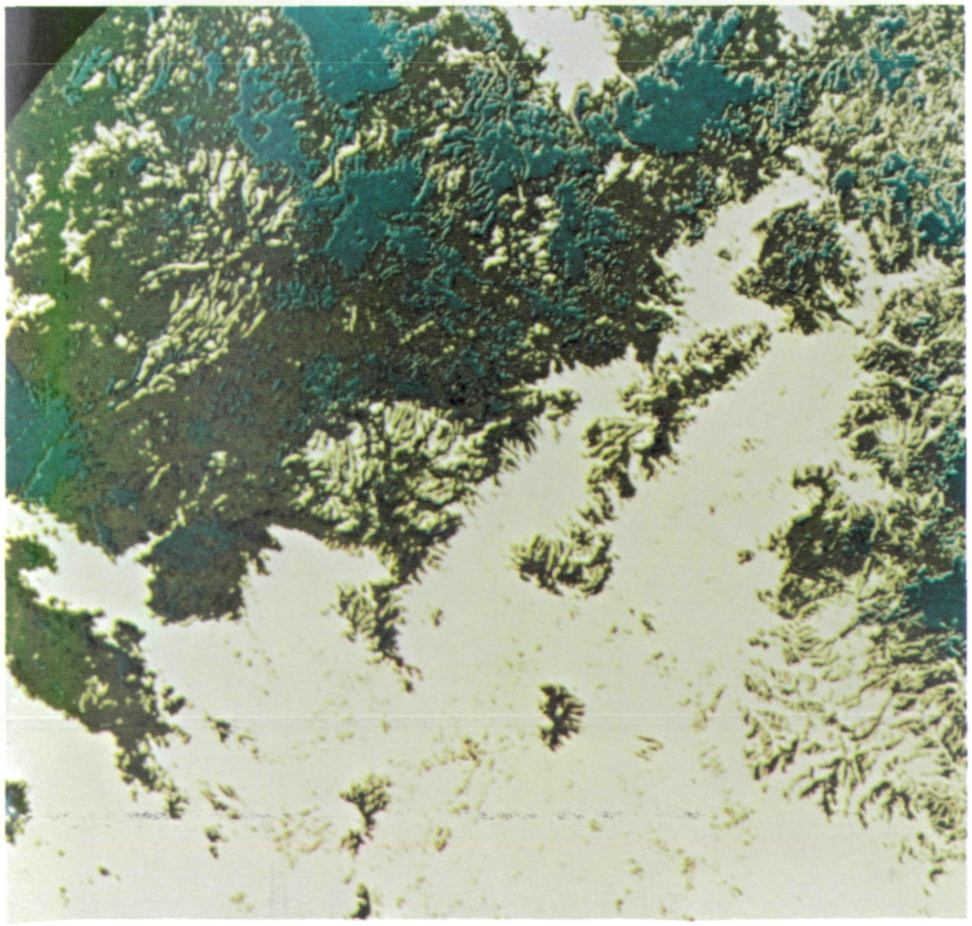




Apollo 7 conventional color photograph of forest fires in northern Australia. An infrared sensor could penetrate this smoke to reveal the extent of the burning area.

Left: Apollo 9 infrared color photograph of Arizona snow scene. Right: Information extracted. The deeper the snow, the bluer its color.





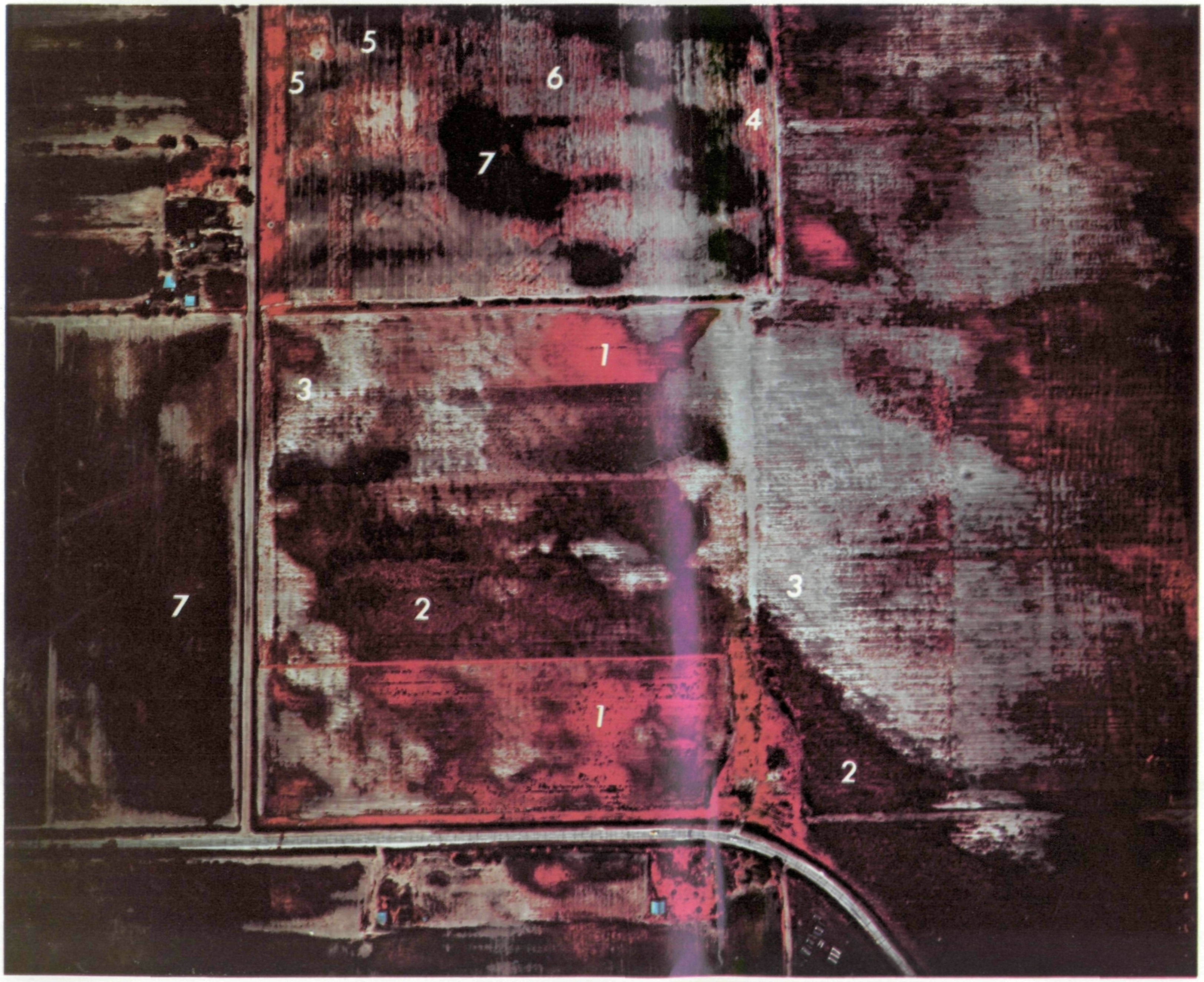
timely information on the yield of crops and timber and status of land available for agriculture. Satellites offer a rapid means of obtaining such information on global and regional bases.

By repetitive observations and reports, satellites can quickly warn monitors of the onset of disease or insect infestation in crops and timber and forest fires in woodland. Satellites can survey wilderness areas to report on plant life there. For example, photographs in the infrared can differentiate conifers from broadleaf vegetation. They can provide information about the depth of winter snowcover in the mountains thereby predicting the extent of spring flooding of the valleys. They might detect water beneath the surface of the Earth, thus expanding the world's vital resource of arable land.

An agricultural survey using high-altitude aircraft photography was initiated in 1971 by NASA for the Department of Agriculture's Corn Blight Watch Experiment.

The program was carried out by the two Federal agencies and selected corn belt states as an experiment for ground and air study of possible southern corn leaf blight during the 1971 growing season. The first phase consisted of black and white photography of selected areas of the nation's corn belt region for use in orienting photo interpreters and field personnel. The second phase was baseline color infrared photography, for use by the Department of Agriculture, to provide a background for an analysis of soil conditions prior to the emergence of the 1971 corn crop. Thereafter, flights every two weeks in the corn belt test areas were scheduled to obtain high altitude color infrared photography. This third phase included, on-the-ground, plant-by-plant inspections of selected corn fields by extension service and agricultural experiment station personnel. The on-the-ground inspections were coordinated with

Identifying soil and crops with infrared: 1) Healthy cotton; 2) Unhealthy cotton; 3) Bare soil; 4) Pig weeds in wet area, minor sorghum; 5) Pig weeds above short sorghum; 6) Dry topsoil between rows of sorghum; 7) Bare soil between rows of sorghum, high moisture content.



the NASA high-altitude photography program, with both the photographs and ground study data being supplied to an interpretation team at Purdue University for analysis.

OCEANOGRAPHY

The ocean is one of the Earth's most important resources. Ninety-five percent of transocean tonnage is by ship. A good proportion of man's food is from the sea. Within and under the oceans lie tons of valuable minerals and vast reserves of oil.

The Earth's several oceans are actually a single world ocean covering about three quarters of the globe. The world ocean acts as a vast energy pump, influencing weather and climate everywhere on Earth. The restless ocean constantly chews away at the continents, changing geography.

Oceanography is concerned with all of this. It is concerned with the physical and biological characteristics of the ocean at all depths, its behavior as a global system, and its interactions with coasts and the inhabitants of these coasts.

Pictures from satellites show the topography of continental shelves and indicate the geography of the ocean floor. They show coastal features, beach erosion, river runoff and sedimentation, ice packs, and unmapped shoals. Analyses of some photographs from satellites have disclosed markings on the ocean surface that indicate the presence of phytoplankton, microscopic green plants that produce seventy percent of the world's oxygen. These microorganisms are also basic to the ocean food cycle. Where there are plankton, there are also fish.

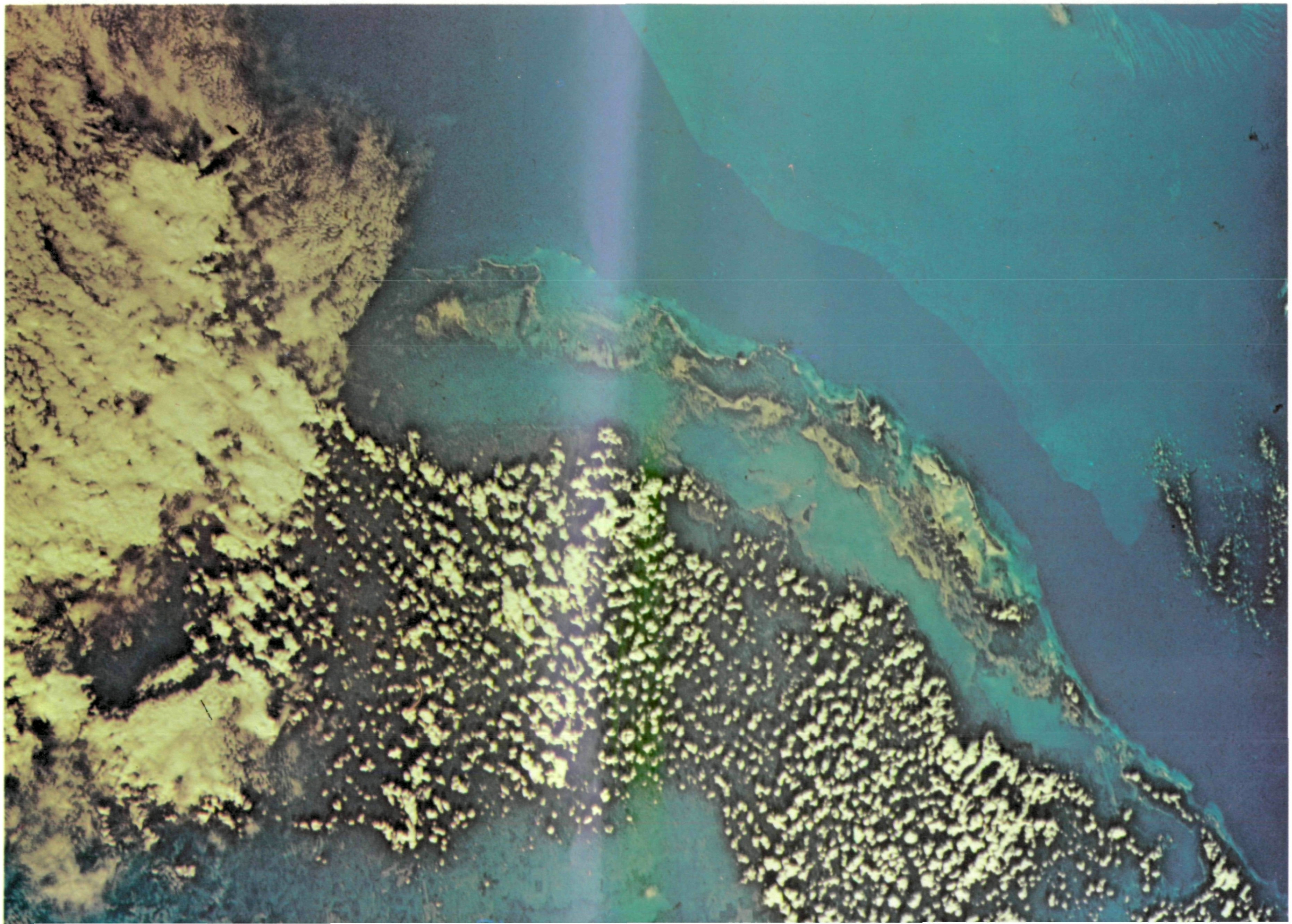
Fish also abound near thermoclines, the corridors between warm and cold ocean masses. Infrared sensing from satellites permits reliable determination of thermoclines. It also detects transfer of heat and moisture from the ocean (information fundamental to meteorology).

Radar sensing can provide information on wave heights and sea state which in turn indicate wind velocities. This kind of information is important both to weathermen and ship captains.

Scientists observe that there are limitations in satellite observation of the ocean. Satellite instruments can see or sense only about one percent of the ocean waters: the part at or near the surface. However, this is the ocean's most dynamic water. Here ships sail, weather is created, and plankton grow.

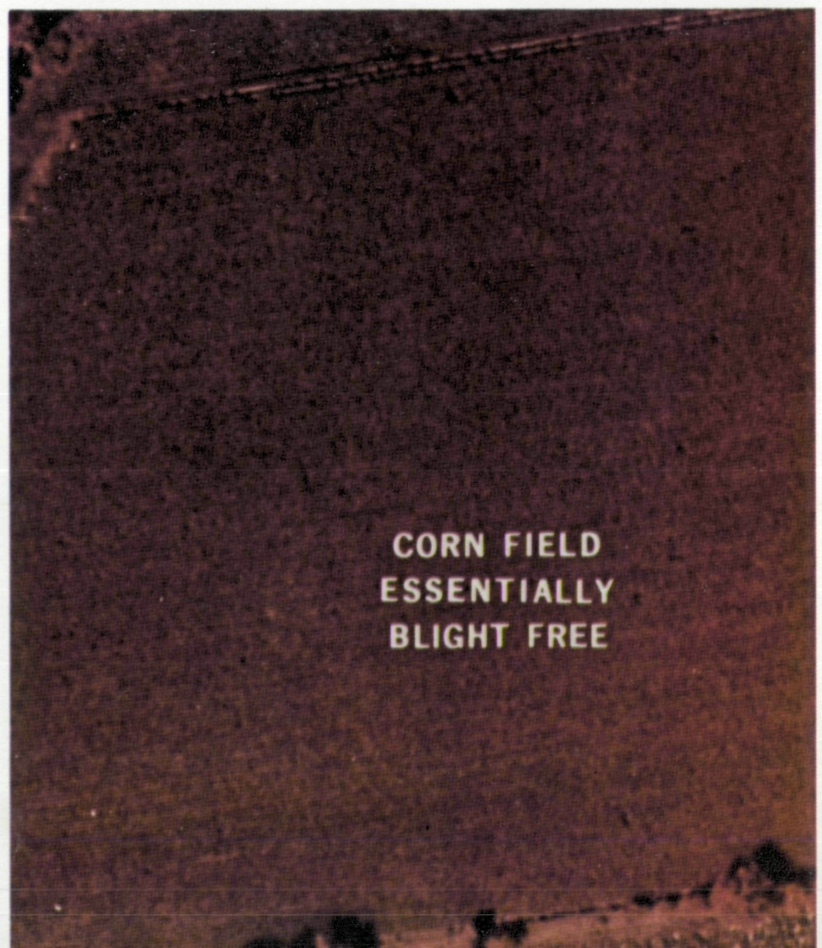
Moreover, the ocean is organized in very specific layers or strata. Strata located well below the surface

Gemini 7 photo shows northern coast of Cuba dotted with clouds, outlying coral islands, reef flats, and shoals, Old Bahama Channel (dark blue), Grand Bahama Bank (light blue), and at upper right, the Tongue of the Ocean (dark blue). The darker the color tone, the greater the depth. For example, the Bahama Bank averages 4½ fathoms, Tongue of the Ocean, 700.



Infrared imagery indicates by darker colors the trees in a citrus orchard infected by brown soft scale.

Southern corn leaf blight studies in infrared.



water sources underground or under the ocean floor, and many others. Such information on both a regional and a global scale will improve man's ability to manage his water resources to the maximum advantage of individuals, industry, and agriculture.

GEOLOGY

In the past three decades, the United States alone has used more minerals and fuels than did the whole world in all previous history. Within the next twenty years, our requirements are expected to double. New reserves must be discovered and an inventory of nonrenewable resources developed for future planning.

A satellite system can help to prospect for minerals on a global basis far more rapidly than any other. Geologists studying ground tones and colors in pictures taken from Gemini and Apollo have tentatively identified new mineral deposits.

Infrared and radar are particularly effective for some types of prospecting. Infrared photographs can indicate the presence of salt domes, which are frequently found near the surface where deposits of oil lie. Radar differentiates between igneous and sedimentary rocks and valuable minerals may be found at the contact between the two. Radar can also disclose hidden faults that frequently are clues to mineral deposits.

With infrared sensing underground hot springs can be discovered. Harnessed to generate electricity, they would help curtail the use of fossil fuels (oil and coal) and reduce the pollution of the atmosphere. Satellites with gamma ray sensors can help find undiscovered deposits of uranium needed to fuel the nuclear electric power plants of the future.

Frequent pictures taken by orbiting satellites can illustrate the slow growth of river deltas, the steadily changing coastlines and river channels, and the creeping of great glaciers. They may also illustrate the imperceptible movement of the continents, verifying the long held theory that continents are drifting like plates on divergent conveyor belts.

According to the continental drift theory, a supercontinent split apart some 150 million years ago, its parts evolved into our present-day continents, and the pieces are still drifting.

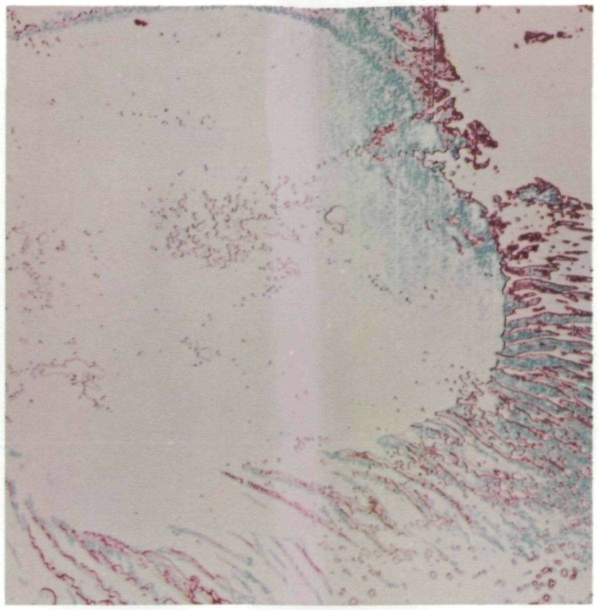
Satellites can also contribute to the long sought earthquake and volcano warning systems that would save thousands of lives annually. Satellite infrared sensors can pick up the build-up of heat inside a supposedly dormant volcano or during a volcano's formative stage.

Earthquakes are global in character and susceptible to global effort. Networks of seismometers, strain gages and tilt meters can radio their messages to orbital satellites as the buildup of stress signals an approaching earthquake. With satellite infrared photography, magnetometers, and radar, geologists will be able to keep a constant watch on fault zones in their entirety. They will be able to note changes in magnetic and gravitational fields and in heat flow that are related to events deep inside of the Earth that cause earthquakes.

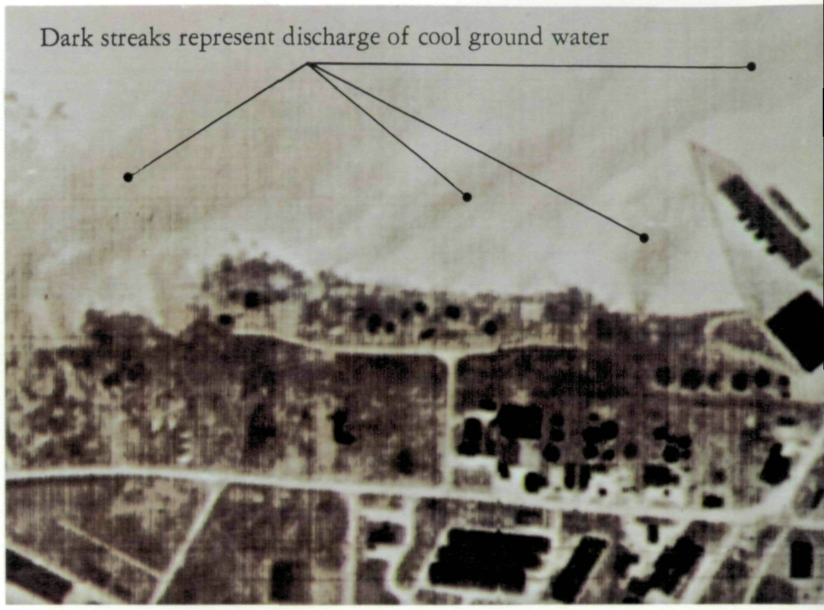
Thus, space technology will truly be brought down to Earth. It will enable us to keep a running record of our planet's condition and a current inventory of its riches—records more precise, more timely, more vivid, and more useful than any we have ever had before. And with the information, we will be able to take the appropriate studied actions for maintaining and improving spaceship Earth for the benefit of all its riders.

Apollo 9 photograph of shoreline between Charleston S.C., and Savannah, Ga., shows such active geological processes as sediment deposition as far as three miles from river mouths and possible offshore shoals (light bands) even farther out.

Isodensity photograph (right) produced by masking original negative of Gemini 5 photograph (left) with fourth generation positive and printing from this combination. The lines represent depth contours on the ocean floor. The red line is two fathoms.



Infrared image of Hilo, Hawaii, shows escape of fresh cold water into ocean.



in one area may be near or at the surface in others. As a result, sensors that can make only surface observations can sometimes yield information about conditions at greater depths.

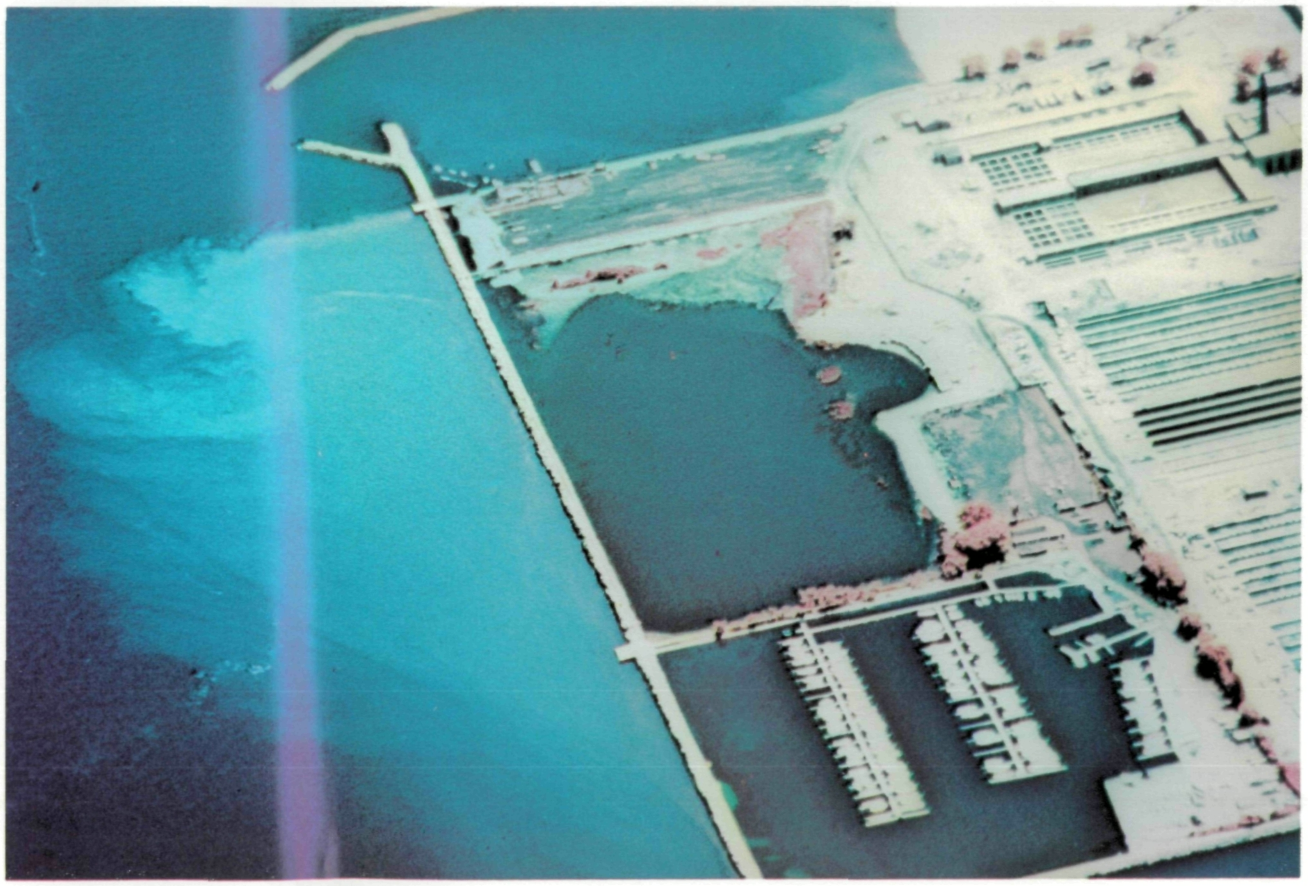
Superimposed upon this factor is the ability of satellites to collect data from Earth-based sensors. Strategically placed buoys can probe ocean levels and phenomena beyond the view of direct satellite observation and send their information back to satellites.

HYDROLOGY

In some parts of the world, fresh water is scarce. Rapidly receding water tables are already threatening the growth of other areas.

Recognizing this need, hydrologists are intensifying their studies of water in the atmosphere and on Earth. They are trying to obtain more information about surface and sub-surface water sources, about locations suitable for building dams and other means of impounding water, and about ways to stop water pollution.

Satellites equipped with multispectral sensors can provide valuable information for hydrologists; drainage patterns, levels of soil moisture and bodies of water, invisible thermal discharges into waterways, extent of water pollution from industrial and urban waste, leaks in reservoirs, undiscovered fresh



5,000,000 gallons of sewage an hour is shown being discharged into Lake Erie from Cleveland's damaged Easterly Sewage Plant. This infrared photo is one of many taken by NASA during the last week of June 1971 to help determine flow and dispersion patterns. NASA's Lewis Research Center was chosen by the City of Cleveland and the U. S. Environmental Protection Agency to conduct this infrared aerial survey because of Lewis' work in exploring the application of remote sensing from aircraft and satellites to the problems of the Great Lakes.

Boston from 51,200 feet. Massachusetts Bay is at northeast corner.
High-altitude photograph taken July 7, 1970.

NASA AERIAL PHOTOGRAPHY FOR URBAN STUDIES

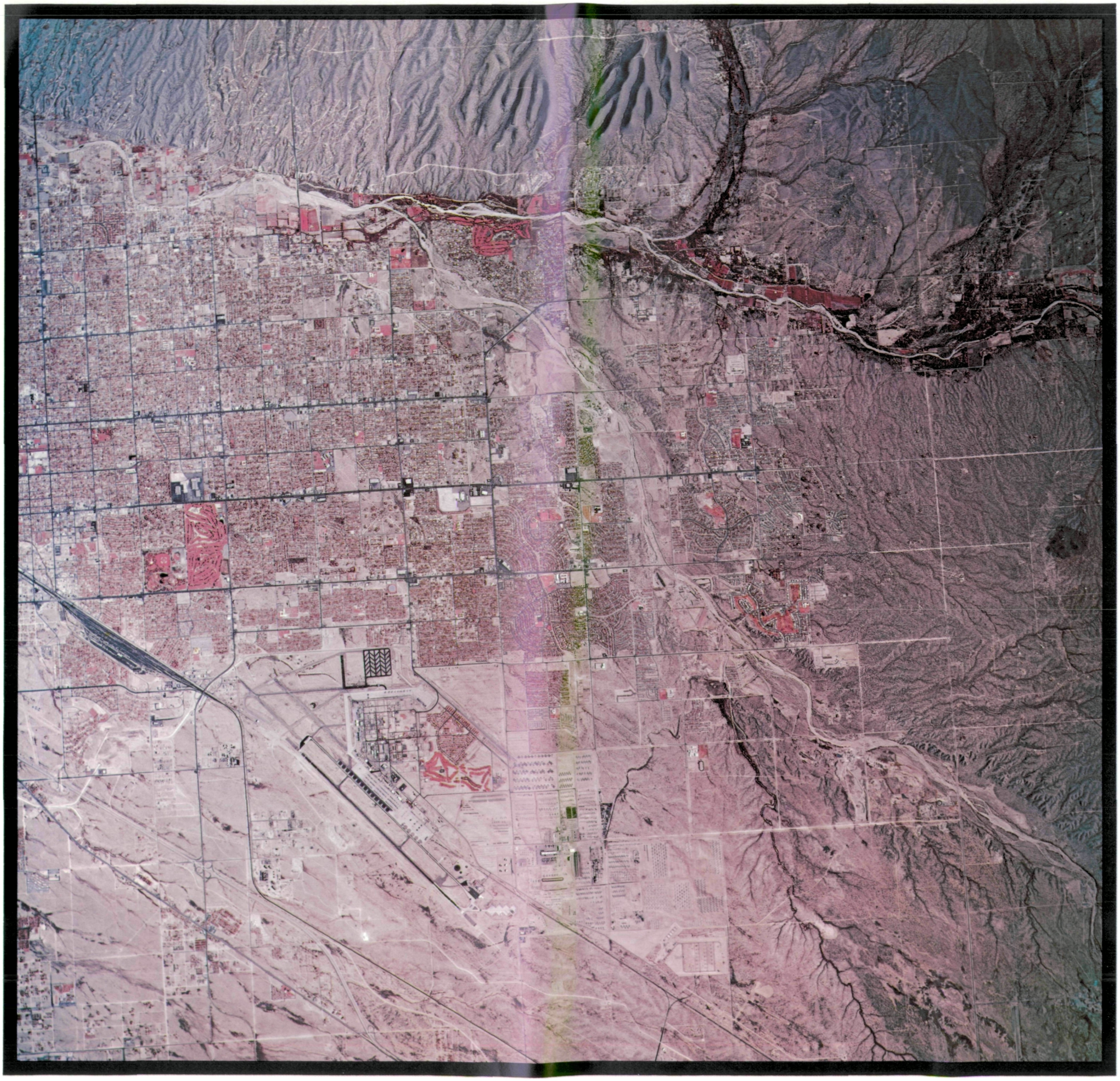
High altitude infrared photographs of major U. S. cities were taken in 1970 by the Earth Observations Division of NASA's Manned Spacecraft Center for a study of land use by the U. S. Geological Survey. The photographs were taken at the time of the 1970 census. Pictures of the same areas will be taken again in 1972 for comparison; the clues provided by infrared photography will make it possible to pinpoint changes.

Washington, D. C., from 50,500 feet. Potomac River is at left. Anacostia River, at right, flows into the Potomac. Taken June 28, 1970.

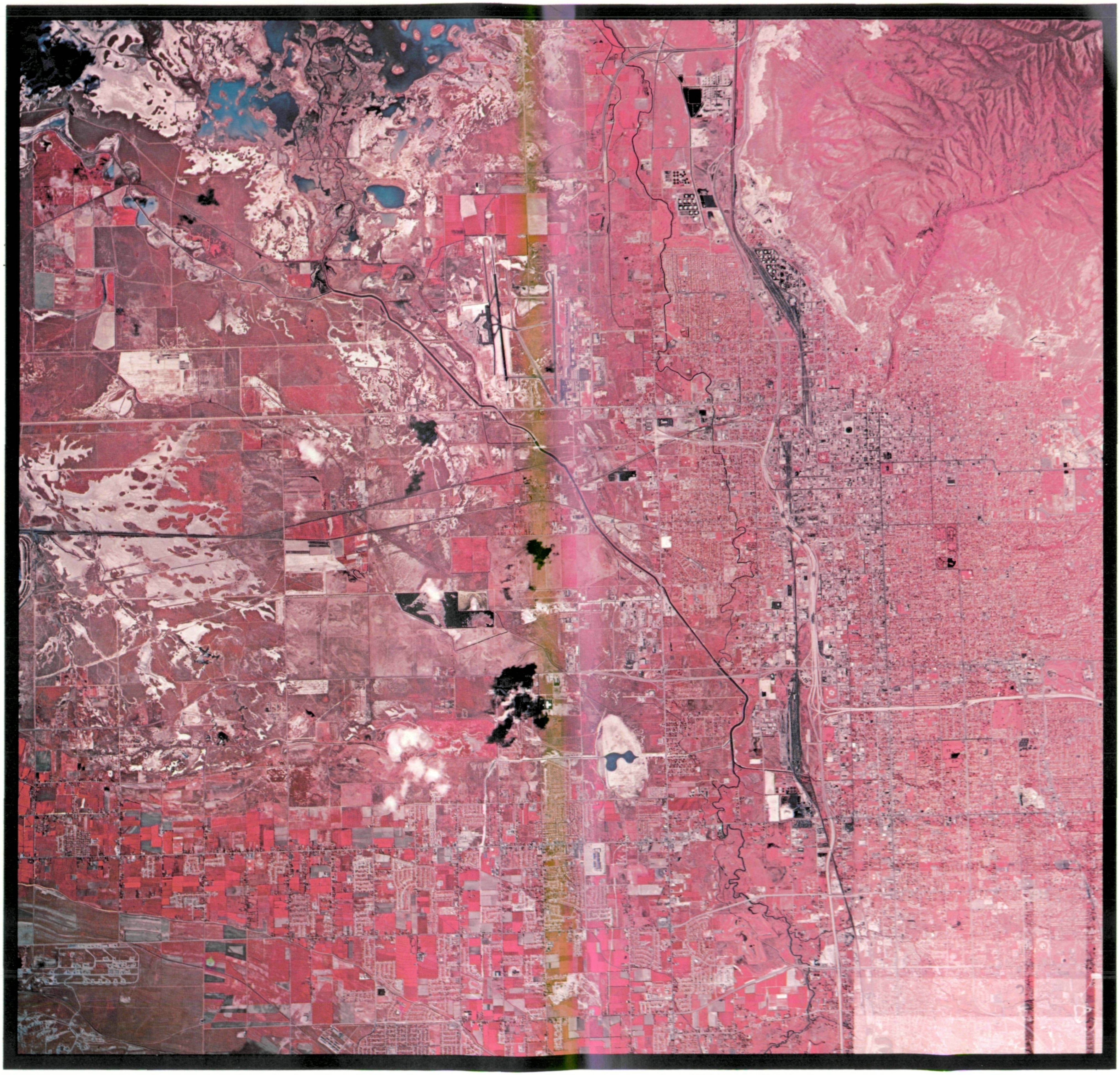
New Orleans, La., taken May 4, 1970, from 50,000 feet.
Mississippi River snakes through urban area.

Richmond, Calif., from 50,300 feet on May 15, 1970.
Berkeley is at lower right. San Francisco is out of view.
Richmond-San Rafael Bridge crosses the Bay.

Tucson, Arizona, area from 49,400 feet. Rillito River, tributary of Santa Cruz, flows westward south of mountains. Pantano Wash flows north-westward into confluence with Rillito. Uniform one-mile square areas are bounded by roads. Taken May 22, 1970.

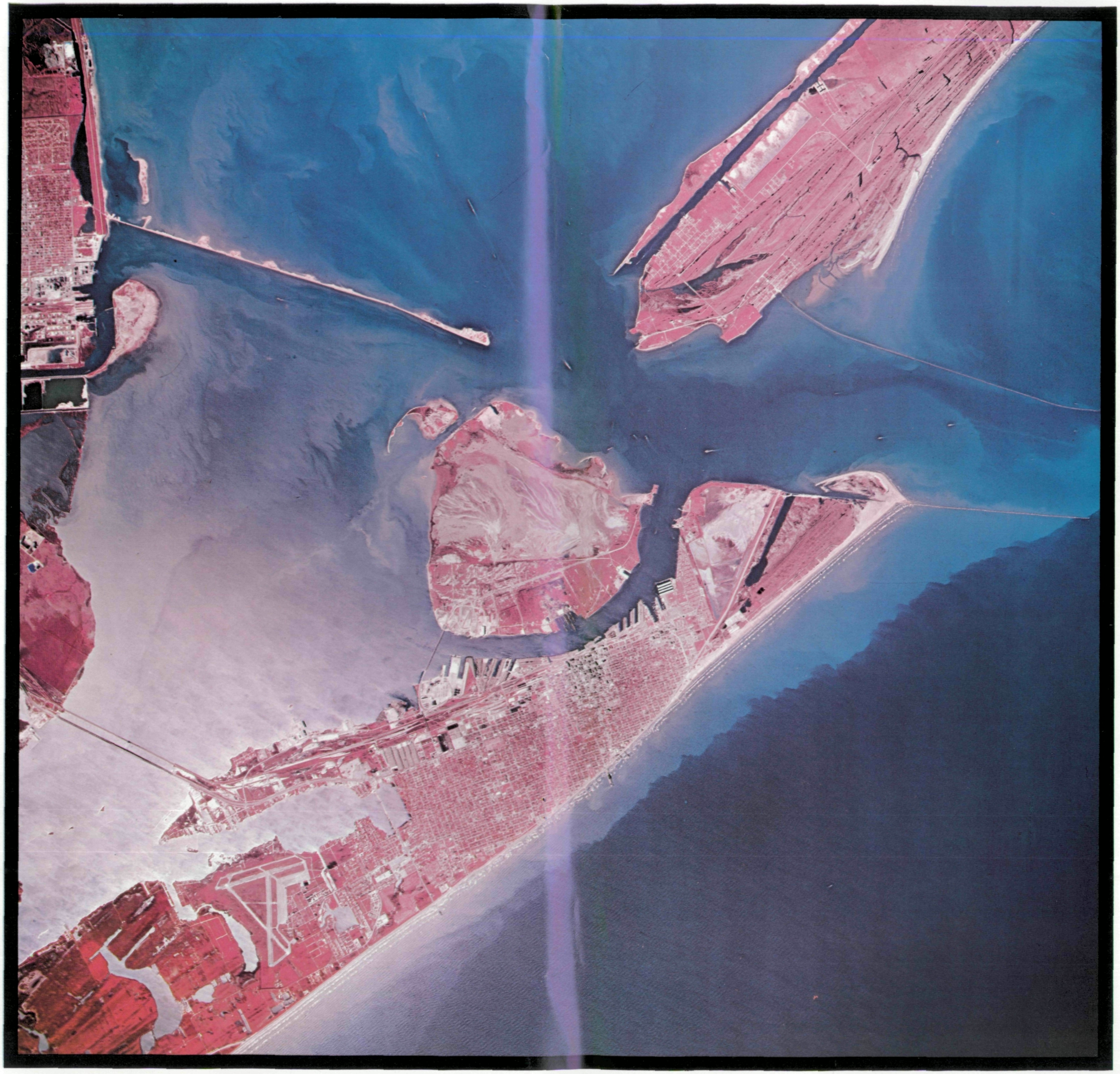


Salt Lake City, Utah, from 51,000 feet, taken May 22, 1970. Note mountainous areas in north.

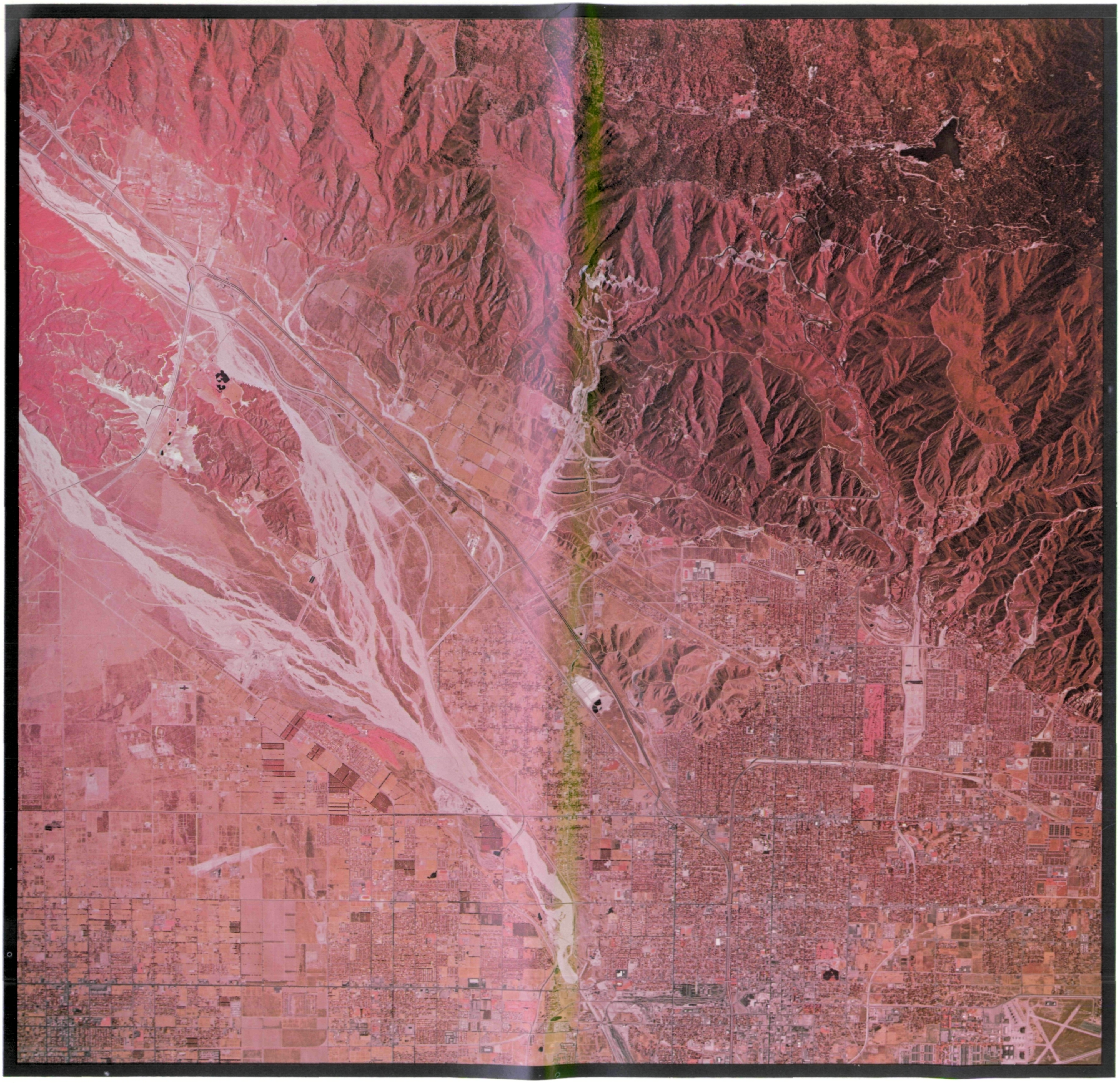


Chillicothe, Ill., from 50,700 feet. Douglas Lake is at right and Goose Lake is below. Taken June 7, 1970.

Galveston and Texas City, Texas, from 50,000 feet on May 13, 1970.
The Texas City Dike extends southeasterly into Galveston Bay.
Interstate 45 connects Galveston Island with the mainland.
Gulf of Mexico is in lower right.



San Bernardino, Calif., from 50,300 feet. The San Bernardino Mountains extend across the northern portion of the photograph, with Norton Air Force Base in the lower right corner. Taken May 14, 1970.



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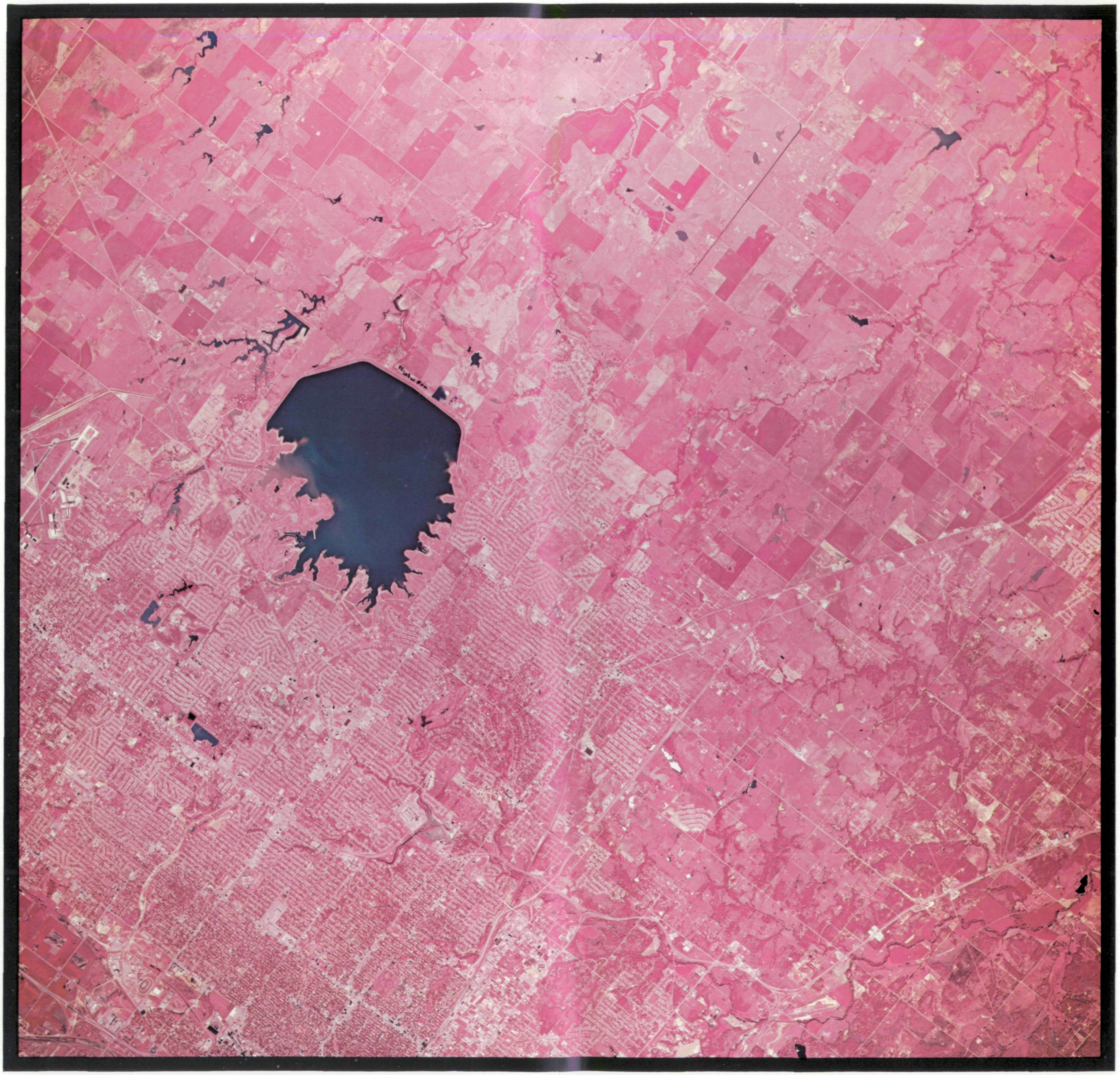
Oklahoma City, Okla., taken May 2, 1970, from 50,000 feet.
The body of water is Lake Hefner.



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ADDITIONAL READING

For titles of books and teaching aids related to the subjects discussed in this booklet, see NASA's educational publication EP-48, Aerospace Bibliography, Fifth Edition.

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